WADC TECHNICAL REPORT 52-101, PART 1

EQUIPMENT FOR TESTING THE CREEP PROPERTIES OF METALS UNDER INTERMITTENT STRESSING AND HEATING CONDITIONS

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WRIGHT AIR DEVELOPMENT CENTER

NOTICES

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EQUIPMENT FOR TESTING THE CREEP PROPERTIES OF METALS UNDER INTERMITTENT STRESSING AND HEATING CONDITIONS

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FOREWORD

This report was prepared by the Institute of Engineering Research, University of California, on Air Force Contract No. AF 33(038)-11502, under Research and Development Order No. R604-304, Design, Specification, and Evaluation Data for Metallic Materials . The work was administered under the direction of the Materials Laboratory, Research Division, Wright Air Development Center, with Mr. E. L. Horne acting as project engineer. This report is the first to be issued on this project. Other reports on the project will be issued as the work progresses.

ABSTRACT

Very little is known about the separate or combined effects of intermittent heating and stressing on the elevated temperature creep and creep-rupture characteristics of aircraft structural metals. Such information is important since aircraft and engines will be subject to these conditions. Between flights, loads and temperatures are low; during flights, they are high. Exact service conditions cannot be reproduced in the laboratory, but arbitrary cycles have been chosen for initial work. In view of the need for more complete information on the effects of such intermittent heating and stressing on the creep and creep-rupture properties of structural sheet materials, an experimental program on this subject was initiated. (Possible theoretical analyses of the results will be made later.) One of the major problems of the program was the development of suitable equipment for the investigation. A description of four creep testing machines, specially designed for this program, with automatic electronic control units is given herein. This equipment is designed to produce any combination, separately or simultaneously, of intermittent heating and stressing of creep-rupture specimens, in or out of phase.

PUBLICATION REVIEW

Manuscript Copy of this report has been reviewed and found satisfactory for publication.

FOR THE COMMANDING GENERAL:

M. E. SORTE
Colonel, USAF
Chief, Materials Laboratory
Research Division

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INTRODUCTION

Most creep data are obtained under exacting conditions of test where the stress (load) and the temperature are maintained constant. These requirements are essential to the obtaining of accurate data in view of the relatively high sensitivity of creep rates to both stress and temperature. Such creep data, however, are often applied to the design of structures which are subjected to variations in the stressing and temperature in service. And, therefore, the important question arises as to how satisfactory constant stress and constant temperature creep data might be as the basis for the design of structures where such simplifying conditions are not obtained.

Unfortunately very little definitive information is available on the effect of variations in stress on the constant temperature creep curves for metals. What few data are known suggest that the subject might indeed be very complicated and not easily resolved. Although more information is known regarding the effect of variations in temperature on constant stress (load) creep data, the effect of various metallurgical conditions on such data have been very incompletely explored. Practically nothing is known about the combined effects of cycling both the stress and the temperature simultaneously on the creep properties of metals.

In view of the need for more complete information on the effects of cycling the stress and temperature on the creep properties of metals, an experimental program of research into this subject was initiated by the Wright Air Development Center. One of the major problems of the program was the development of suitable equipment for this investigation. The following report covers the development of four creep testing units for cyclic stress and cyclic temperature creep testing.

DESCRIPTION OF MACHINES

Four creep testing machines were designed and constructed for evaluating the creep properties of metals under conditions of cycling the stress and cycling the temperature. These machines, their automatic electronic control units and their autographic recording units are shown in the photographs of Figures 1A and 1B respectively.

The requirements for smooth operating automatic control of the stress and temperature cycles were predicated on observations that creep data are sensitive to variations in these factors. For example, a copper alloy containing 3% nickel and some silicon was previously reported not to fail when loaded slowly over a period of two to three hours, even when the applied stress appreciably exceeded the static ultimate tensile strength(1). Although this effect might have been due to precipitation hardening, it nevertheless illustrates the need for uniformity in loading creep specimens. Additional tests on a steel which had a relatively stable structure at the test temperature also revealed differences in the creep curves which were probably attributable to differences in loading the specimens(2). Perhaps some of the differences in the creep resistance of a single alloy reported by different laboratories arise from differences in the loading procedures which were used. Undoubtedly, under the conditions of cyclic stressing, the effects of loading and unloading differences are repeated and therefore become magnified and exact reproducibility of the loading and unloading histories becomes important. Furthermore there have been several

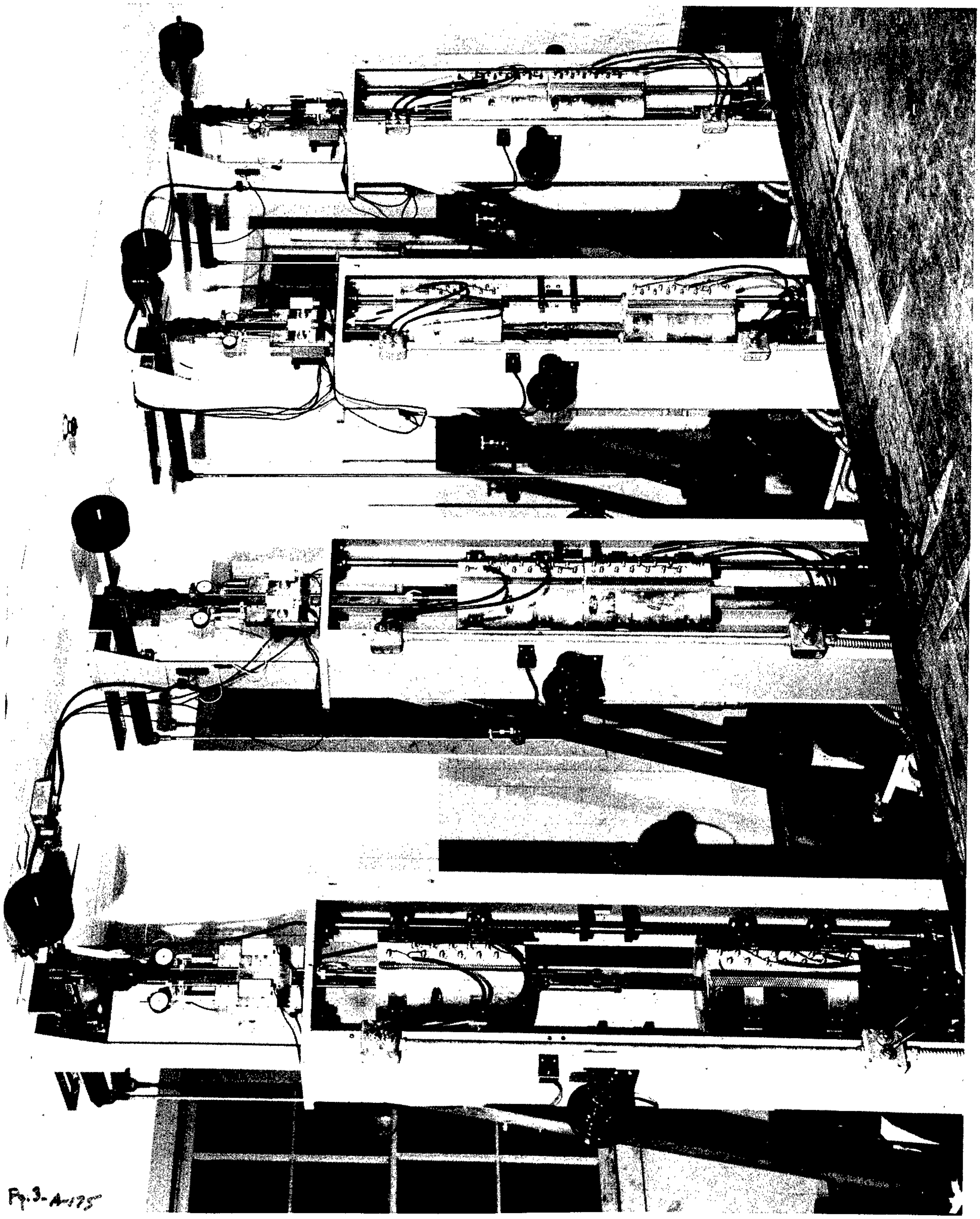

Figure 1A Cyclic Creep Testing Units

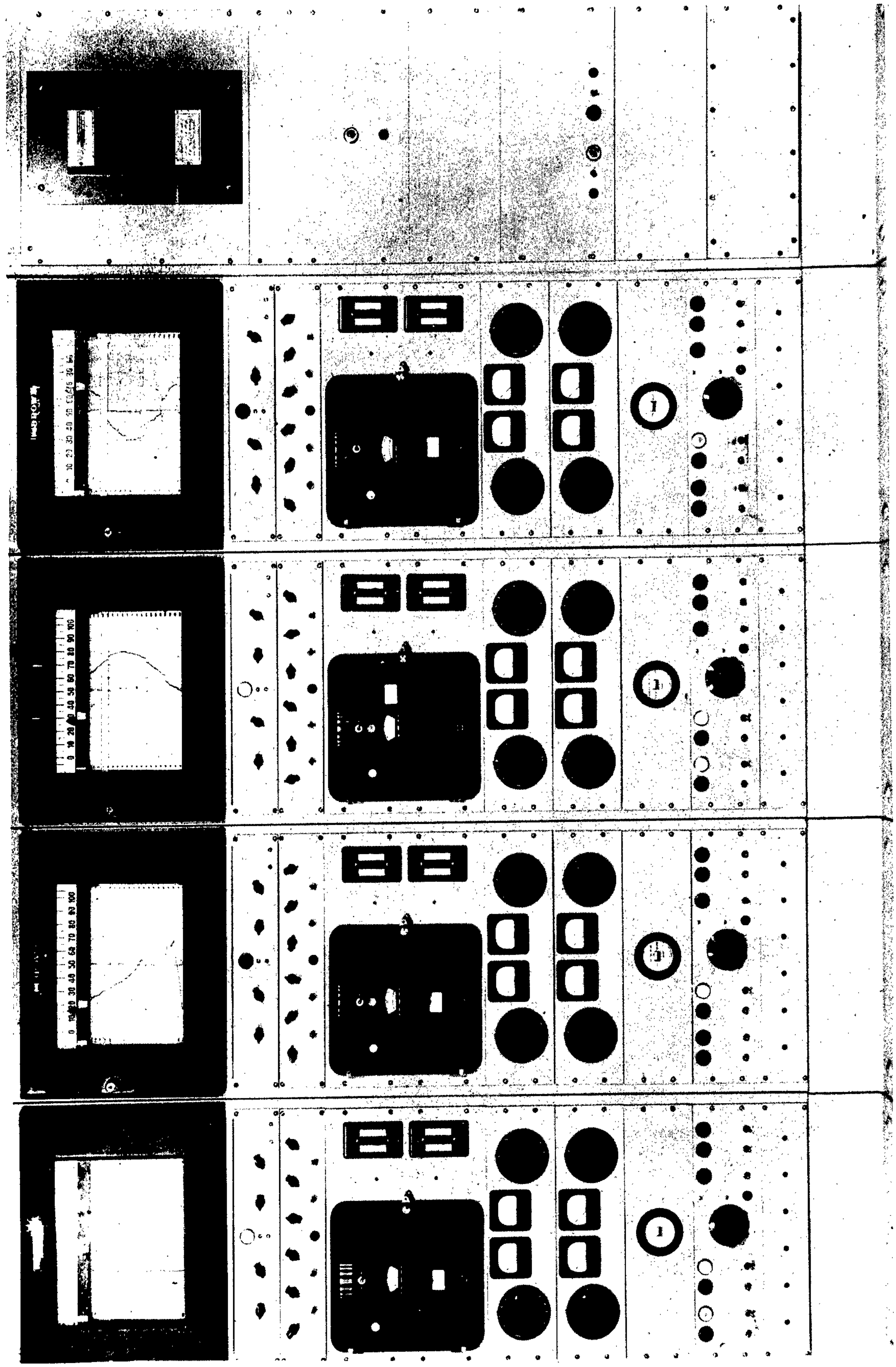

Figure 1B Controlling and Recording Panels reports in the literature suggesting superimposed vibrations of stress[3] accelerate creep. Thus it becomes important to provide the machines with high inertias and smooth loading operations.

An outline of the design and construction of the units will be given in this section of the report whereas the working details will be elaborated in the sections that follow.

The basic design of the present machines is not markedly dissimilar from the design of common types of tensile creep testing machines, as illustrated in the photograph of Figure 2. A vertical column supporting a horizontal lever arm is mounted on a high inertia concrete base which in turn is insulated from ground vibrations by double isomode pads between the high inertia concrete base and the concrete floor. The concrete floor, which was cast directly on the ground, is about three feet below the wooden working floor. This was done in order to separate the creep units from the building structure and thus reduce the transmission of floor vibrations to the units. The higher elevation of the working floor area also permits easier accessibility for mounting the specimens and adjusting the units. Weights for loading the specimens are placed on a weight pan suspended through a pin at the back of the 10 to 1 ratio lever arm. Adjustable counterweights have been placed on the front of the lever arm in order to facilitate compensation for the dead load of the lever arm as well as the additional loads arising from the auxiliary fixtures for mounting the specimen and the strain gages. In order to reduce the objectionable and variable effects of friction inherent in conventional designs, a sensitive flexure plate was substituted for the commonly used knife edge at the fulcrum of the beam as is shown in the photograph of Figure 3. For the

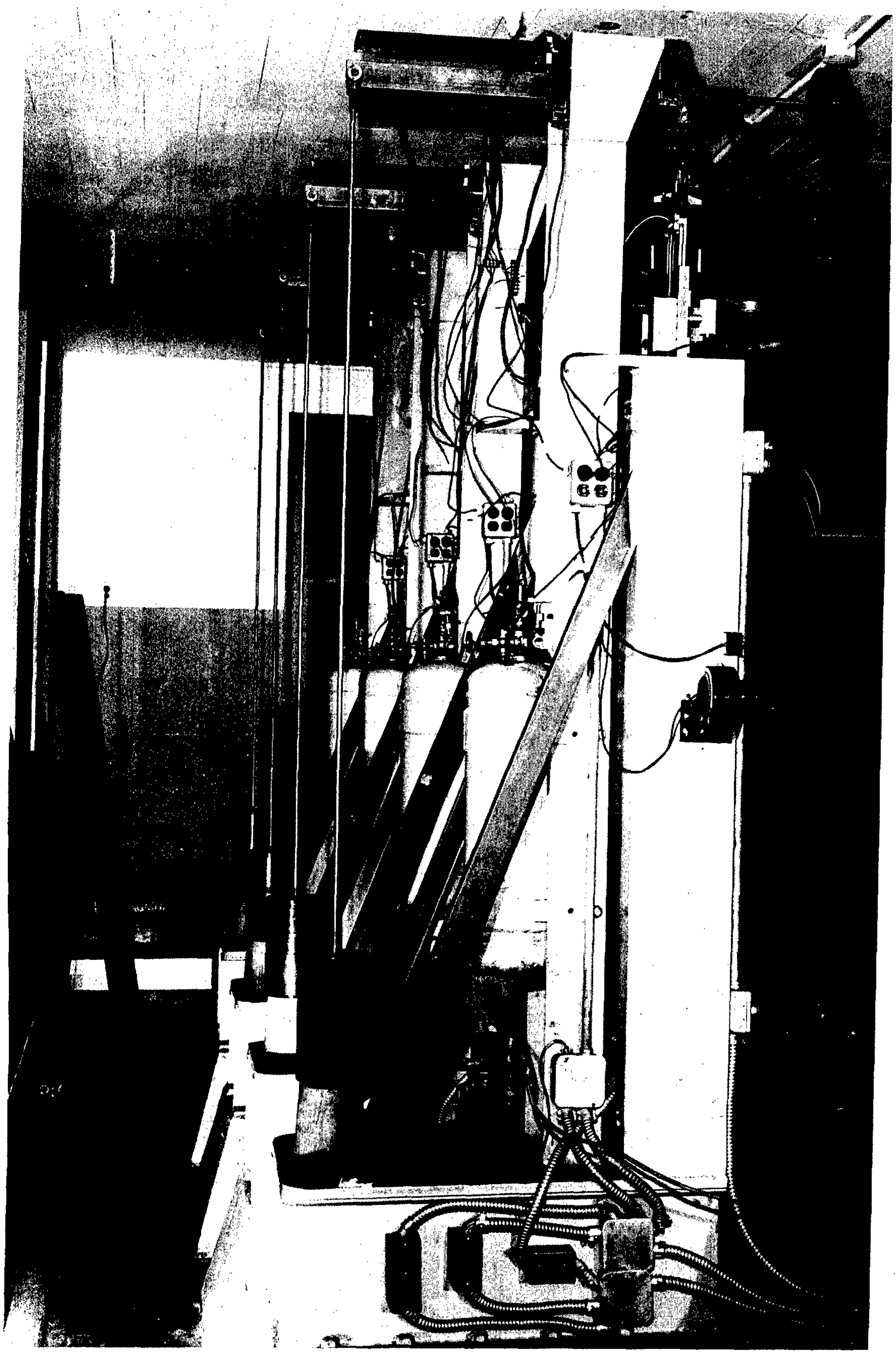

Figure 2 Side View of Testing Units

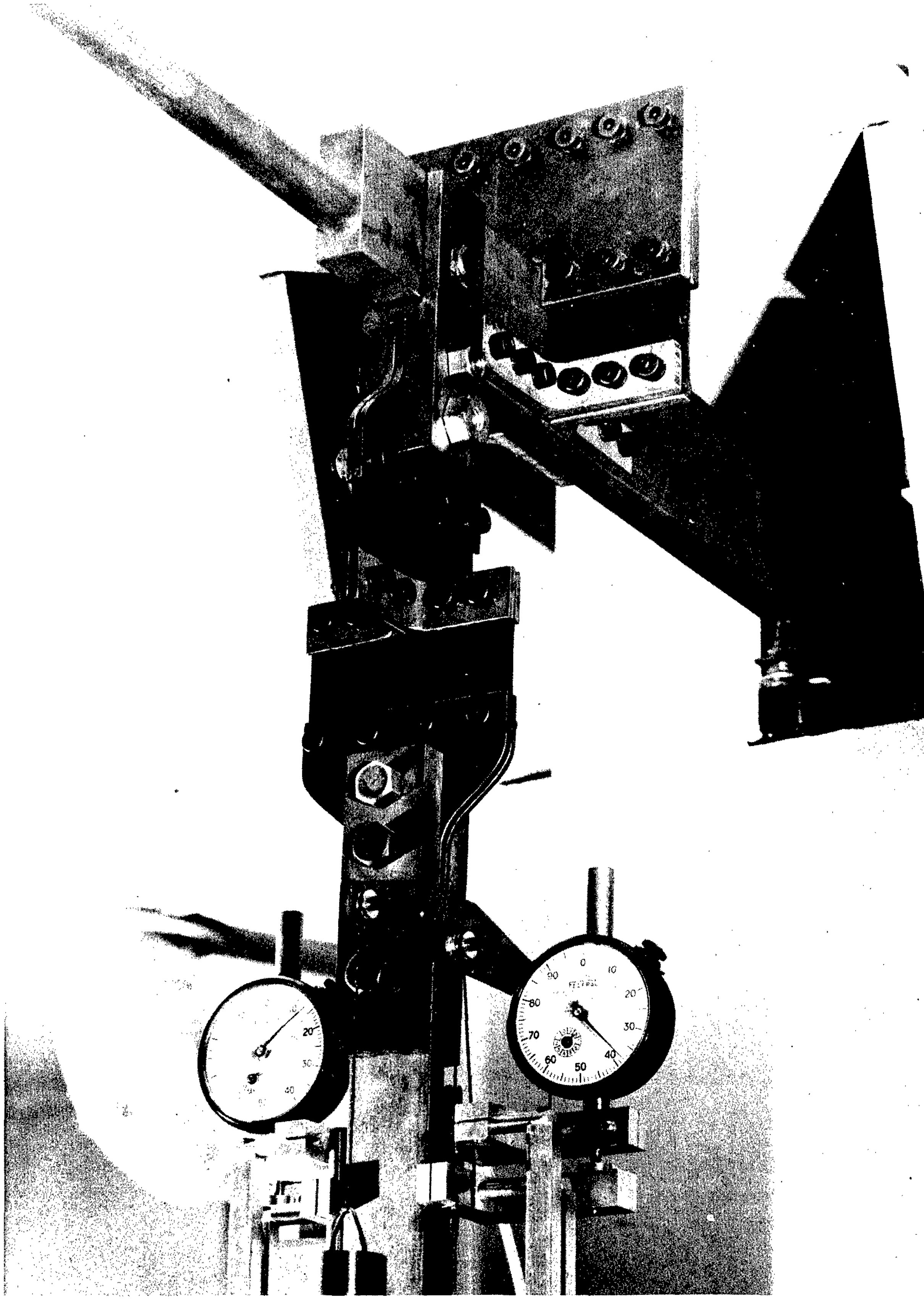

Figure 3 Fulcrum And Alignment Flexure Plates

same reason a set of two sensitive orthogonally aligned flexure plates were substituted for each of the two universal joints commonly employed in series with the specimen in order to reduce the bending of the specimen and thus permit pure tensile loading. Tests on repeated loadings and unloadings, including removal and remounting of the specimens, have revealed consistently uniform results on axial stressing of the specimen, thus verifying the satisfactory results obtained by these innovations.

As shown in Figure 4, the specimen is mounted to the lever arm through pin jointed pulling tabs and two sets of orthogonal flexure plates. The lower pulling tab is attached to the spider shown at the bottom of the photograph of Figure 4. The vertical position of the spider is fixed by the motion of a piston in an hydraulic cylinder placed under the frame of the creep unit. As the piston is lowered, the specimen moves downward causing the back of the lever to elevate, thus lifting the weights, as shown in Figure 2, from their pedestal and applying a load to the specimen. When the lever is balanced a micro switch cuts off the power to the pump. In this way smooth loading with a minimum of irregular jerky loading is obtained, as revealed by experimental stress determinations. Unloading is accomplished in the reverse manner; the piston, moving upwards, resettles the weights on their pedestal thus removing the load from the specimen.

The above description gives the basic design of the cyclic stress creep testing machines.

Details of construction and operation will be considered in the following order:

(A) Loading and Unloading

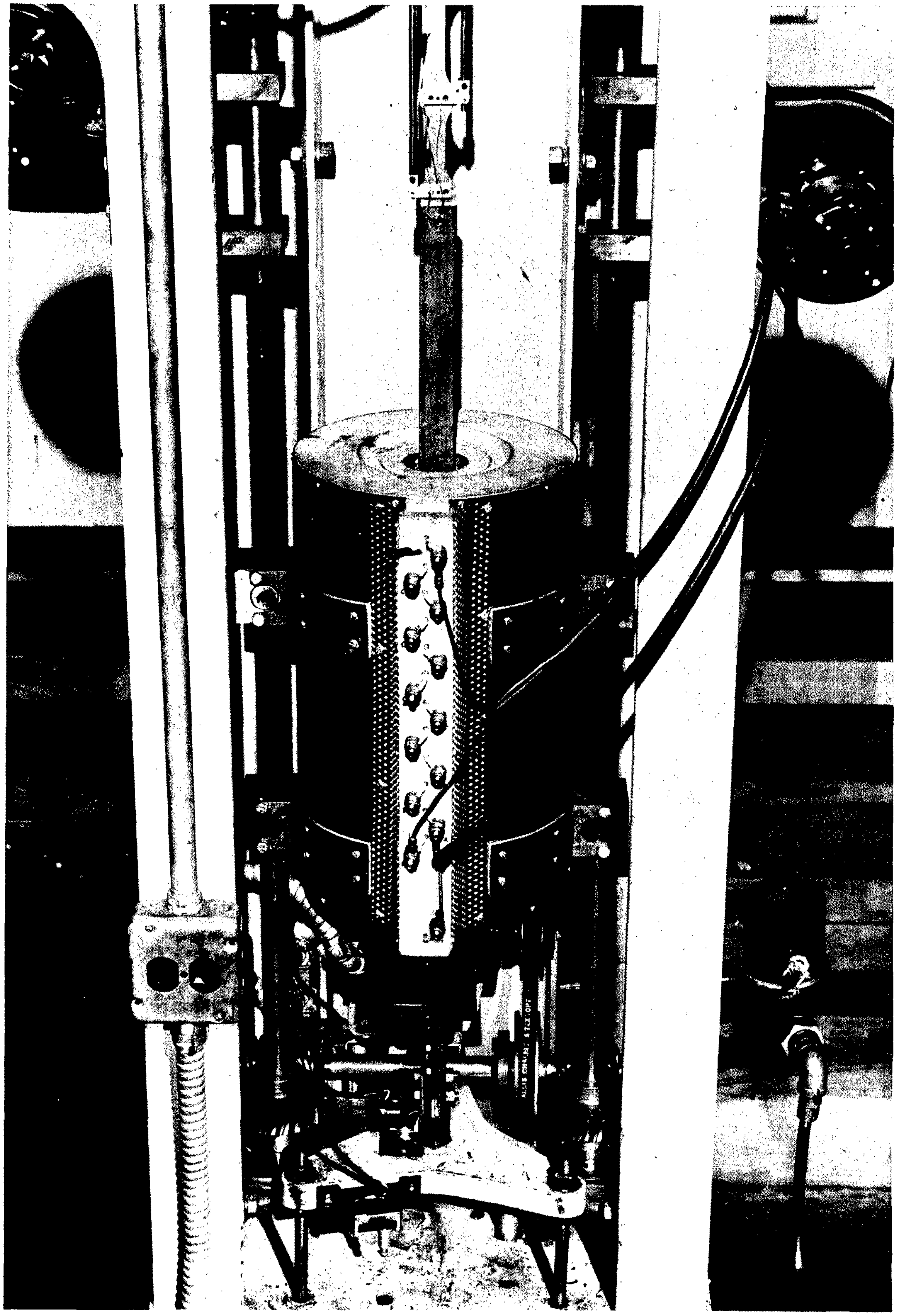

Figure 4 Lower Specimen Mounting and Spider

(B) Furnace Design and Temperature Cycling

(C) Specimen Design

(D) Automatic Recording Apparatus

(A) LOADING AND UNLOADING:

The portion of the system involved in the loading operations is shown schematically in Figure 5. A motor driven gear pump is used to apply a head of oil to the loading piston. The loading piston is attached to the lower end of the specimen, and extends the specimen on downward movement. The specimen is connected to the weights through the lever arm linkage. A load limit microswitch which stops the loading operation at completion is located beneath the lever arm near the fulcrum.

In the unloaded position, the loading piston is at the top of its travel. The weights are resting on their pedestal, and the normally open load limit microswitch is maintained closed by the lever arm. When either the manual or automatic loading switch is closed, the circuit is completed to the gear pump motor and oil is supplied to the loading piston at a constant rate. The loading piston is forced downwards, thereby loading the specimen. The load on the specimen is increased steadily until the weights are raised from their pedestal. The pump continues to operate until the lever arm is in level position. The load limit microswitch is set to open at this point and the operation of the pump is stopped.

The rate of loading is controlled by a needle valve, and the oil pressure behind the needle valve is maintained constant by a bypass relief valve built into the pump. A check valve prevents oil from flowing back from the pump while the specimen is under load.

The lever arm is kept at level position throughout the load cycle

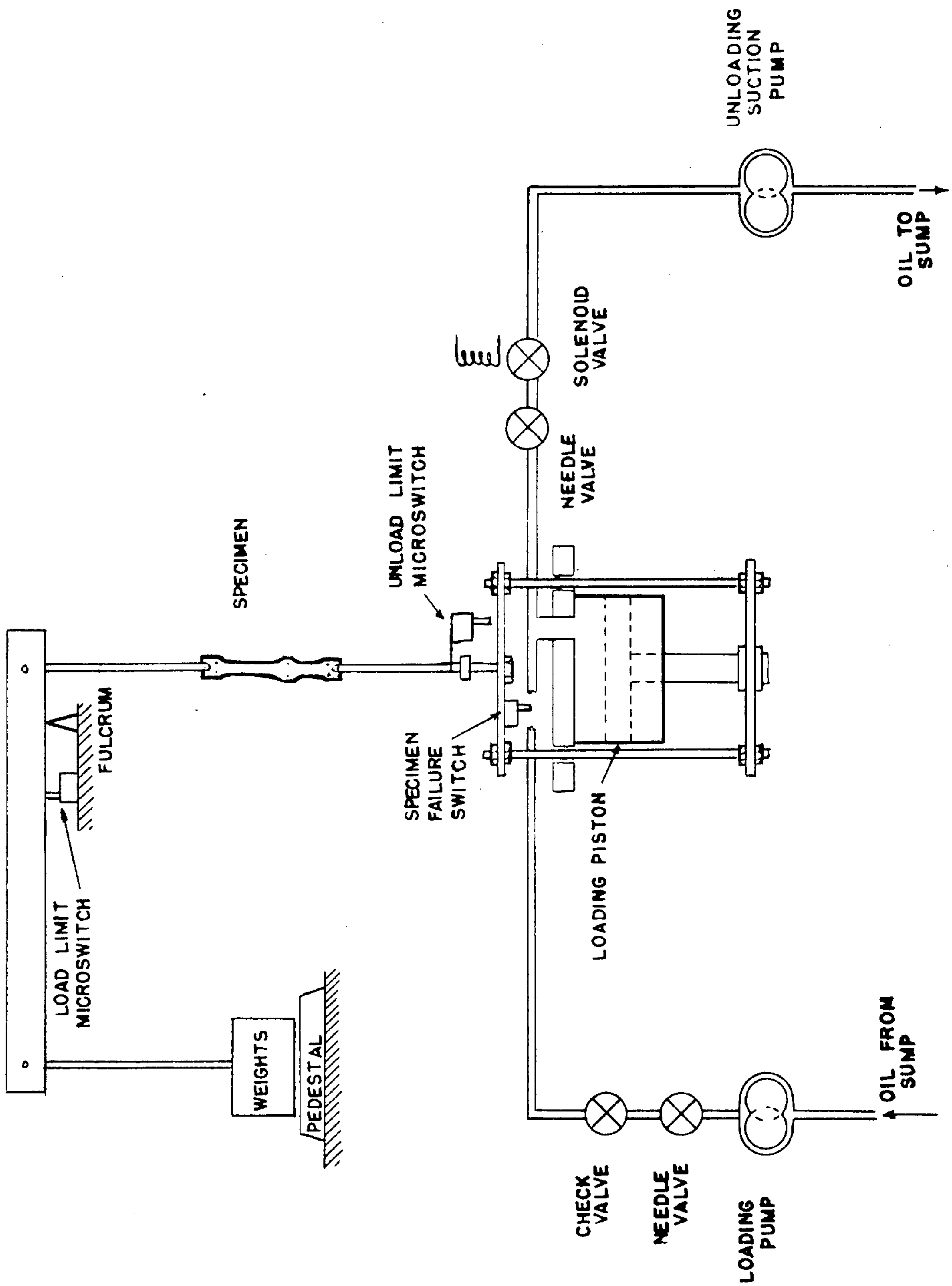

Figure 5 Schematic Representation of Loading and Unloading System

by the action of the load limit microswitch. As the back end of the lever arm is lowered, due either to specimen strain or oil leakage, the lever closes the switch and the pump operates until the arm is brought back to the level position at which time the switch again opens.

A schematic layout of the unloading portion of the system is also shown in Figure 5. A normally closed solenoid valve maintains a closed pressure system until unloading begins. Upon manual or automatic time clock switching, the solenoid valve opens, and simultaneously the motor driven suction pump begins operation, gradually relieving the pressure on the loading piston and drawing it upwards. The rate of flow of oil from the piston is controlled by a needle valve. As the piston is raised, the weights at the back of the lever arm are lowered to their pedestal. Unloading continues until the load on the specimen is completely relieved. At this point, the normally closed unload limit microswitch is opened, closing the solenoid valve and stopping the pump operation.

A switch located at the side of the machine enables the operator to by-pass the unload limit microswitch and operate the suction pump manually. The loading piston can thus be raised to any desired position. Its purpose is to facilitate the insertion of new specimens.

A specimen failure switch connected to the loading piston stops all operations of the machine and associated controlling and recording devices after the specimen breaks.

(B) FURNACES AND TEMPERATURE CYCLING:

The nichrome wound resistance type furnaces used in this investigation differ from those ordinarily encountered in creep apparatus in that they are made in two halves, split horizontally as shown in Figure 1A. In operation, the furnace halves are brought together to heat the specimen, or separated to facilitate specimen cooling. Each half contains two separate windings with individually variable power supplies. Furnace calibrations made over the extended specimen length demonstrate that temperature uniformity within one degree Fahrenheit is readily obtainable under steady state conditions.

The furnaces are controlled by Leeds & Northrup Electromax Controllers; resistance type units into which are incorporated adjustable heat impulse rate and proportioning band circuits. The temperature sensing element is a platinum resistance thermometer located near the specimen in the upper furnace.

The furnaces are mounted on a pair of motor driven lead screws which were designed with a reciprocating thread so that the furnaces may be brought together or separated with the motor driving continuously in the same direction. Limit switches automatically stop the driving motor when the furnaces reach the open or closed positions.

Temperature cycling is accomplished by closing the furnaces to bring the specimens to the high temperature and opening them to allow the specimen to cool to room temperature. The furnaces remain at the high temperature throughout the cycle. Blowers mounted on the machine frame to either side of the specimen operate during the room temperature portion of the cycle to accelerate specimen cooling. As in the case of load cycling, temperature cycling may be done either manually, or automatically by means of the sequence timer.

Although rapid cooling of the specimen is readily achieved by this device, the rate of heating with the present furnace arrangement is such that about eighty minutes are required to bring the specimen to within five degrees Fahrenheit of the steady state temperature. However, several possible solutions to this problem are being reviewed, and it is expected that higher heating rates will be obtained before the experimental phases of the program involving temperature cycling are undertaken.

(C) SPECIMEN DESIGN:

A tandem type specimen shown in Figure 6 is being used throughout these tests. This specimen design was adopted in order to eliminate the usual difficulties encountered in maintaining rigid clamping of the extensometers to the specimen under conditions of high temperature creep testing over relatively large strains.

The specimen is made with two reduced sections, one three inches long and the other one inch long. Identical shoulders are machined at the ends of each gage section. The extensometer arms are clamped to the shoulders rather than over the gage length itself as is commonly done. The elongation of each section is recorded separately, and the elongation of the shorter section is subtracted from the elongation of the longer section in order to get the net elongation over the central two inch gage section of the longer section.

It is assumed in the use of this type of specimen that if the contours on each gage section are identical, the elongations in the fillet regions and the shoulders are subtracted out in obtaining the net elongation in two inches. A considerable amount of reported testing experience with tandem type specimens has shown that this assumption is in fact correct.

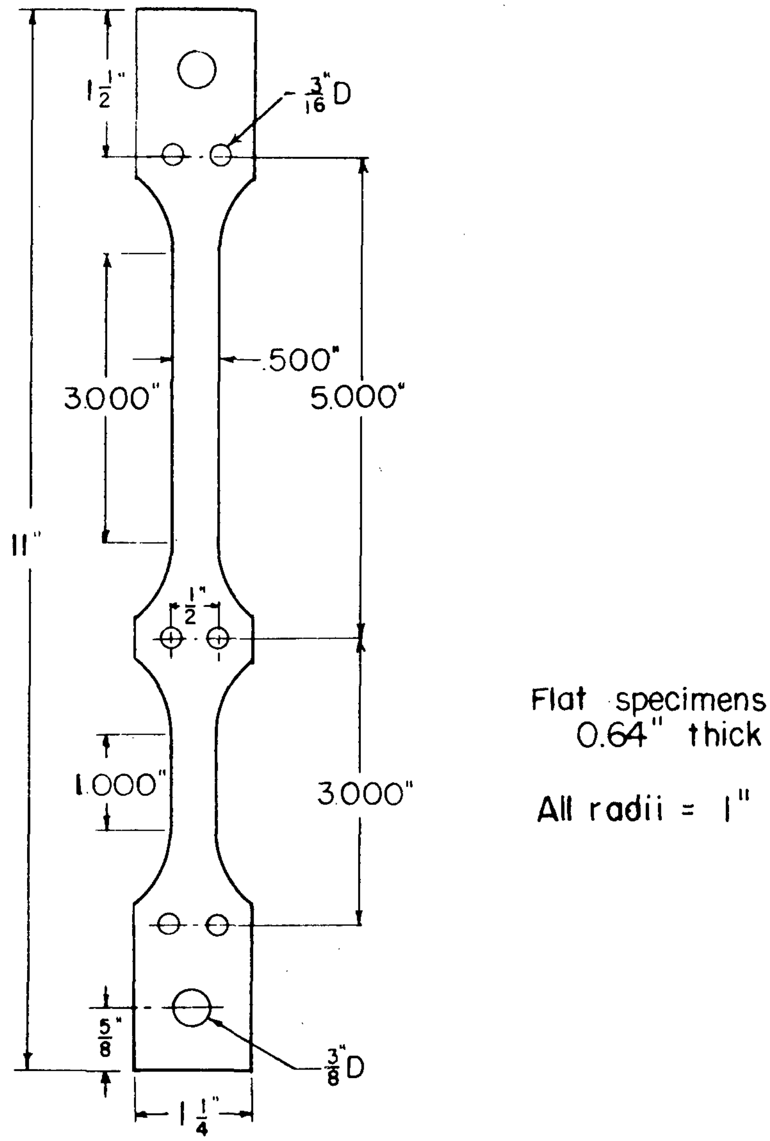

Figure 6 **Tandem Specimen Design**

To avoid the introduction of spurious strain results, it is necessary that the cross sectional areas of both gage sections be the same. To maintain uniformity, all specimens are machined in a jig constructed specially for this purpose. Gage section widths are kept uniform within a tolerance of one half thousandth of an inch.

The rigid mounting of the extensometer arms to the specimen is shown in the photograph of Figure 7. In the mounting of a specimen of this type, precaution must be taken to assure equal stress on both reduced sections. As will be noted in Figure 7, the extensometer arm mounted at the center section of the specimen as well as the associated strain gage components tend to exert a small additional stress on the upper gage section, but not on the lower section. To eliminate the effect of the unbalanced stress, the extensometer arm to the center of the specimen is counter-balanced so that it will move up or down with equal ease. Thus the only additional load introduced by this arm is the very small one to overcome the friction of the counterweight pulleys.

(D) AUTOMATIC RECORDING APPARATUS:

Temperatures at three points along the specimen and the elongations of both the one and three inch reduced sections are recorded continuously and automatically by a twelve point Brown "Electronik" recorder. During each twenty-four second print cycle, temperature at each of the three points is printed once, elongation in the short section, three times, and elongation in the long section, six times.

The recorder circuit was revised to increase the sensitivity of the detecting and balancing systems, and to permit simultaneous recording of both strain and temperature.

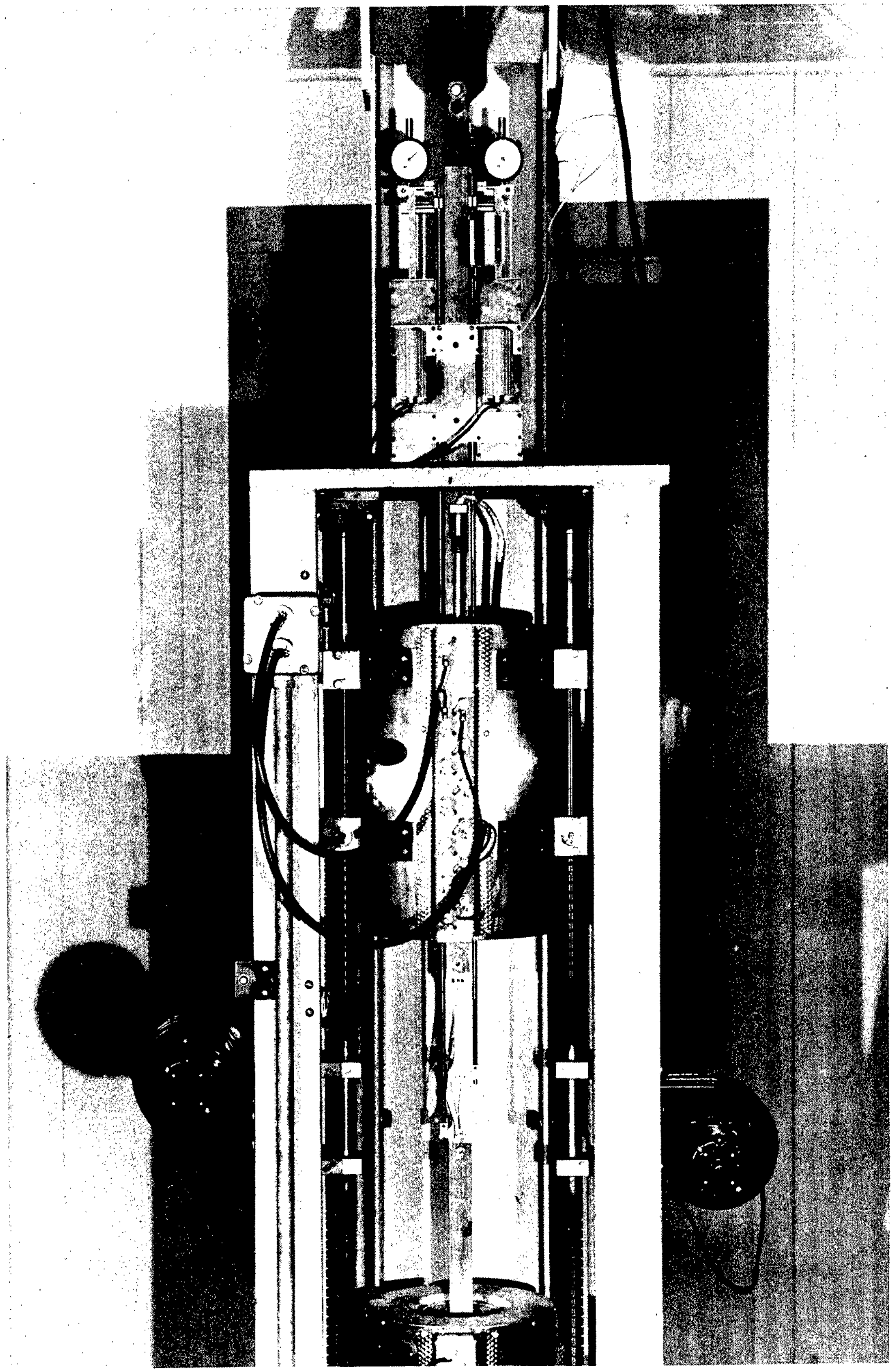

Figure 7 Extensometer Mounting

In order to obtain high accuracy in temperature recording, zero suppression circuits were introduced into the potentiometer circuit which subtract out the larger portion of the thermocouple voltage in steps of four millivolts. Thus, the width of the chart is used to record only a small part of the temperature (one hundred twenty-five degrees with the iron-constantan thermocouples being used) and specimen temperatures may be read with ease to an accuracy of one degree Fahrenheit.

Each recorder is provided with two such suppression circuits to permit the recording of temperatures in the vicinities of both the test temperature and room temperature. During the automatic temperature cycling, a switching relay connects one circuit as the furnaces close and the specimen heats, and the other as the furnaces open. A complete and accurate record of temperature during cycling is thus obtained.

A small, thermostatically controlled heater in an aluminum block serves as the thermocouple cold junction. The couples are set in wells in the block, and accurately maintained at a constant temperature well above the ambient atmospheric temperatures ordinarily encountered.

The elongation measuring and recording systems are shown photographically and schematically in Figures 8 and 9. Elongations in each section of the specimen are recorded separately and subtracted subsequent to the test to find the net elongation over the central two inches of the longer section. Dial gages are mounted in parallel with the automatic strain recording devices as shown in Figure 8 so that measurements may be checked periodically, or strains read manually in case of failure of the automatic equipment.

The system of strain recording adopted for use in these experiments

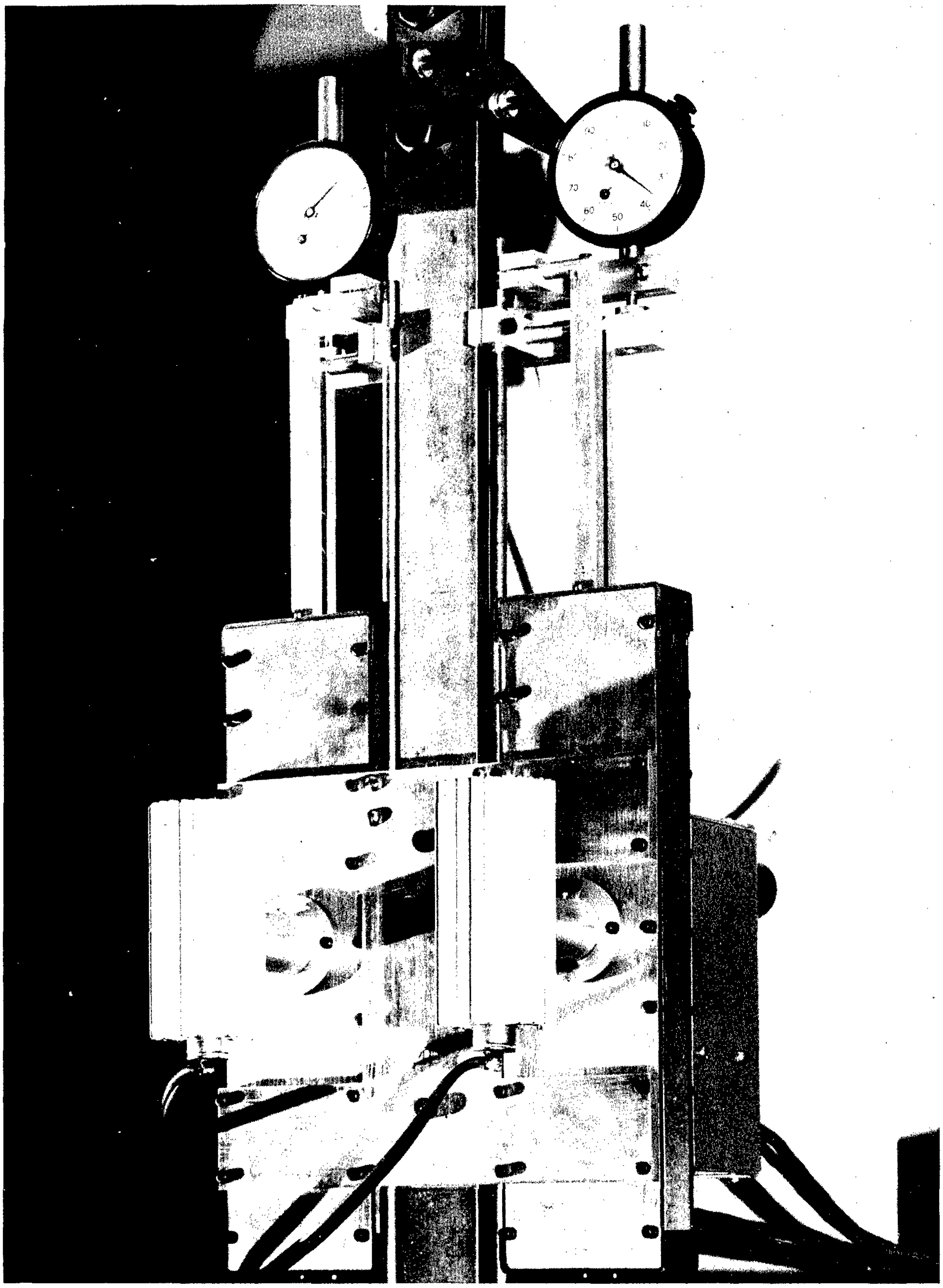

Figure 8 Strain Gages

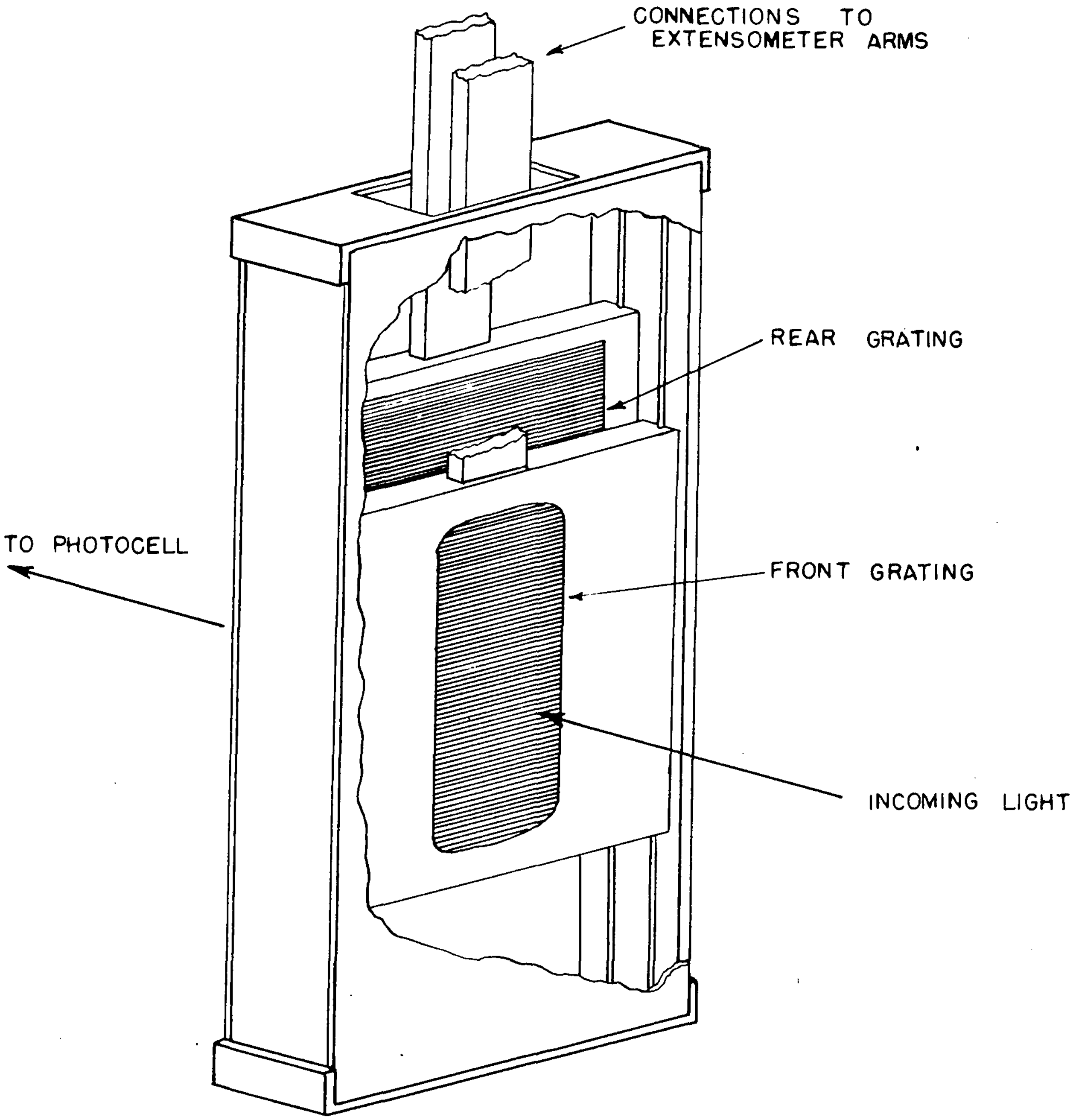

Figure 9 Detail of Grating Arrangement for Strain Recording

is rarely encountered, though not new, and relatively simple in operation. It consists, basically, of two ruled glass gratings which are displaced parallel to one another as the specimen strains. The gratings are attached by the extensometer arms to either end of the specimen gage length. The lines and spaces on the gratings are of equal width, each being five thousandths of an inch. Light passing through the gratings is caused to vary periodically in intensity as the specimen strains; from maximum brightness when the lines on the two gratings are superimposed upon each other, to maximum darkness when the lines on one grating are opposite the spaces on the other. This periodic intensity variation is registered on a photo cell, the output of which is fed to the twelve point recorder. The resulting strain record appears as an angular wave, with elongations of five thousandths of an inch magnified to the width of the chart. One set of gratings is connected with each gage section of the specimen, so that two elongation records are produced on the chart. Examples of the strain and temperature chart records for constant and cyclic load tests are reproduced in Figures 10 and 11 respectively.

The advantage of this method of recording is immediately apparent. Instead of limiting the entire strain record to the width of the chart, a folded record, such as this apparatus in effect produces, permits the recording of large strains to great accuracy. Furthermore, calibration of the devices over the entire expected strain range is not necessary, as the sensitivity remains constant regardless of the strain.

DISCUSSION

A comprehensive summary has been made of the operation of creep testing units for the study of the effects of stress and temperature

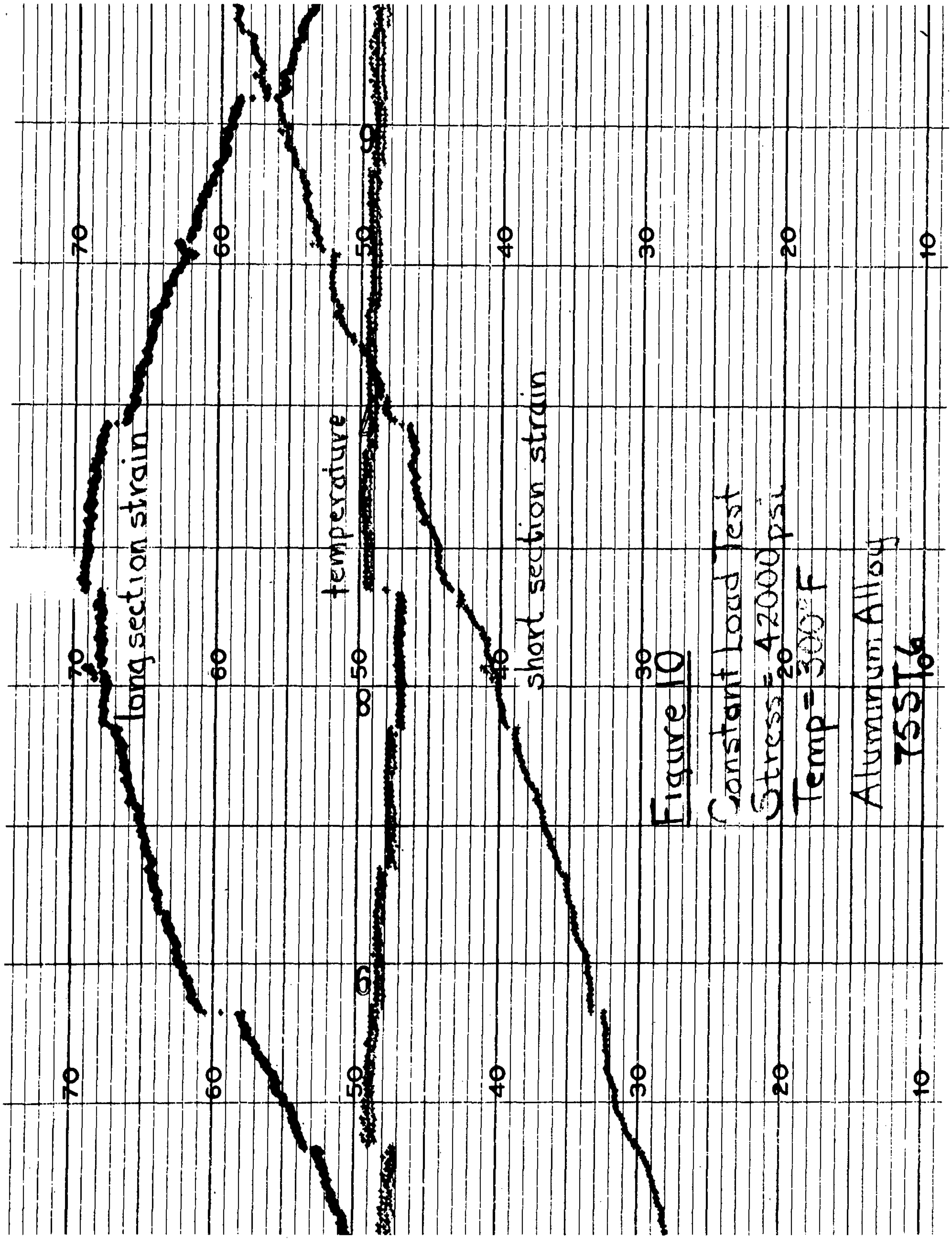

Figure 10 Typical Strain and Temperature Recording for Constant Loading

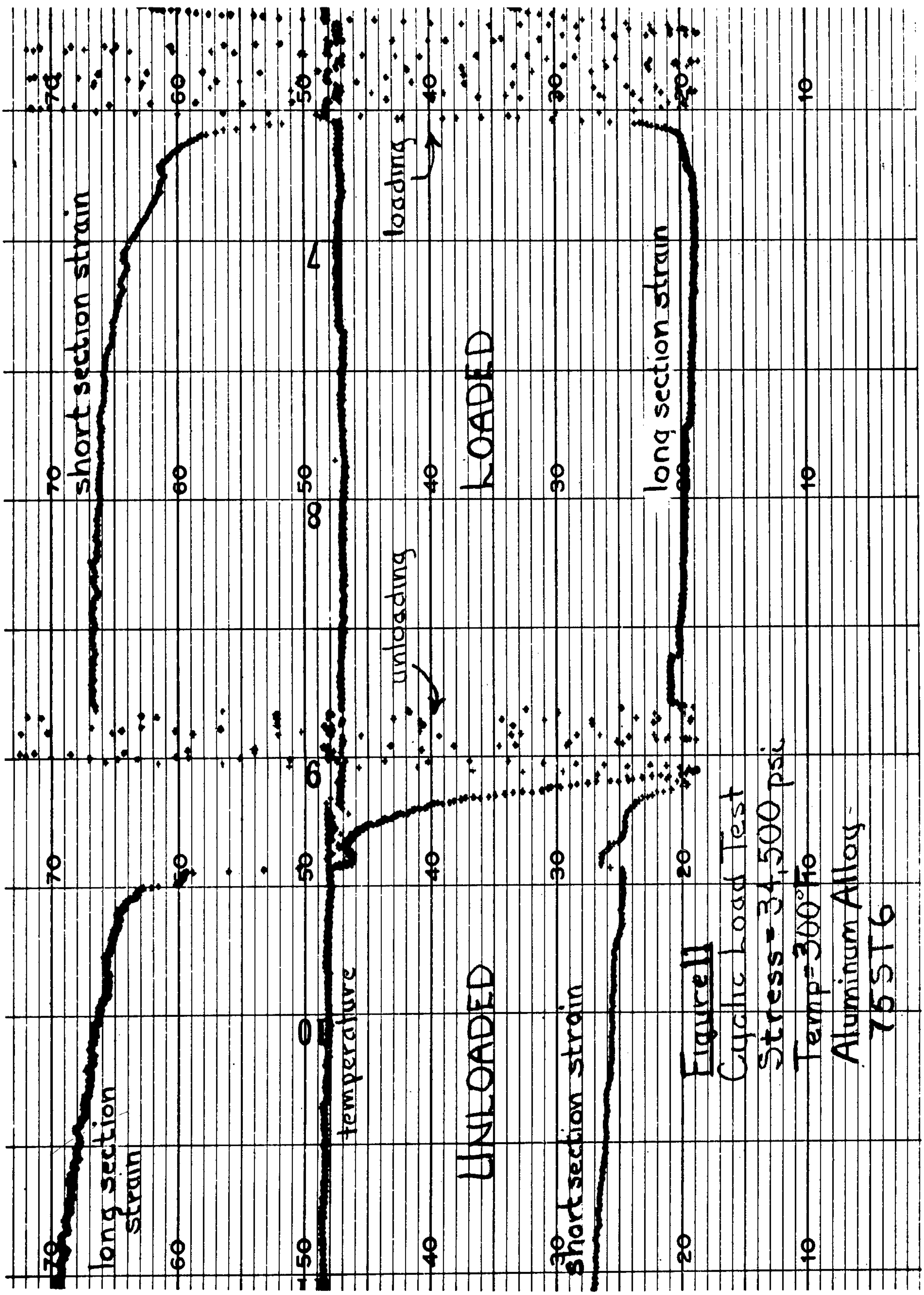

Figure 11 Typical Strain and Temperature Recording for Cyclic Loading

cycling on creep strength. The machines are completely automatic in performance, and the data is continuously recorded. Considerable attention has been given in the body of this report to the many innovations introduced into the design of this equipment to assure accurate results.

It may be mentioned here that the equipment is at present being used in the steady and cyclic load testing of the aluminum alloy 75ST6. Despite the apparent complexity of the machines, their operation is found to be relatively simple, and very satisfactory.

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